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# Application of Low Potential Electric Fields for Improving Slope Stability

Pasquale Armillotta[a], Benedetta Pastarini[b], Andrea Segalini[b], Gessica Umili[c]*

[a] *Dep. of Earth Sciences, University of Parma, Italy*
[b] *Dep. of Environmental and Territory Engineering and Architecture, University of Parma, Italy*
[c] *Dep. of Earth Sciences, University of Turin, Italy*

**Abstract**

The aim of this research is the application of low potential direct currents in order to improve slope stability by inducing the reduction of potential swelling and water content, and the precipitation of carbonates in cohesive soil pertaining to a possible sliding surface. Two different types of tests were performed: the first one on small samples and the other one on a physical model reproducing a slope. Main results showing the effectiveness of this application are described.

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*Keywords:* low potential electric field; swelling reduction; slope stability; soil slip.

## 1. Introduction

By applying a potential difference to a saturated porous medium, some phenomena are induced, e.g. electroosmosis, electrokinesis, electrophoresis and hydrolysis. In the past, some attempts to use electroosmosis for stabilizing landslides in cohesive soil have been performed by applying potential difference in the order of 100 V/m. However, this technology has been quickly disregarded due to the fast degradation of the electrodes, the high costs of the system, the insufficient knowledge of the induced phenomena and the side effects (soil warming, colloidal fraction reduction, induced cracking) (Veniale, 1978). The present study aims to verify the applicability and the effectiveness of low potential direct currents (10 – 20 V/m) for improving slope stability in case of cohesive soil and shallow sliding surface (i.e. soil slip). Thanks to the recent scientific and technological development, and the new materials, low potential electric fields could become effective tools for:

* Corresponding author. Tel.: +39-011 6705114.
*E-mail address:* gessica.umili@unito.it


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1) reducing potential swelling in active clay minerals;
2) inducing dewatering in cohesive soils;
3) facilitating carbonates precipitation in soils in which an alkaline environment is induced.

This could enable the improvement of soil shear strength and therefore, the improvement of the slope safety factor.

## 2. Reference to real case studies: the soil slips in langhe area

Authors considered soil slips phenomena that occurred in Langhe Area (Piedmont, Italy) as reference models for this study. These phenomena affected the shallow part of slopes in which marl formations and sandy layers alternate (Regione Piemonte, 1998). Sliding surface is usually located in a layer with thickness which varies from 0.1 – 0.4 m (Chiappone, 1999), composed by destructured soil due to physicochemical alteration induced by water. Veniale et al. (2002) observed that in this layer illites are iso-oriented, while smectites assume a spongy morphology that induces soil volume and swelling pressure to increase. Veniale et al. (2002) also observed marl decalcification in favor of a percentage increase of clay minerals and other mineralogical variations concerning marl destructuration (Table 1). Consequently, shear strength value decreases in the sliding surface (Simeoni, 1998; Chiappone, 1999).
Samples used to perform laboratory tests consist of Viadana silt, a sandy clay loam (74% silt, 13% clay, 13% sand) very similar in terms of grain size, mineralogy, mechanical property, geotechnical characteristics, carbonates content and Methylene blue value (VB), that is a semi quantitative index of potential swelling in a cohesive soil, to the soil found in the sliding surfaces of soil slips in Langhe area (Table 1).

## 3. Experimental research

In order to verify the effectiveness of the proposed treatment with low potential direct currents (10 – 20 V/m) for improving slope stability in case of cohesive soil and shallow sliding surface, two different types of tests were performed: the first one on small samples and the other one on a physical model reproducing a slope, all composed of Viadana silt.

Table 1. Comparison between characteristics of Viadana silt (Gabrieli et al., 2008; Armillotta, 2015) and of soil samples in correspondence to the sliding surface formed in a slope in Monastero Bormida (Simeoni, 1998)

| | Viadana silt | | Soil sampled at Monastero Bormida* |
|---|---|---|---|
| | GABRIELI et al. (2008) | ARMILLOTTA (2015) | SIMEONI (1998) |
| Grain size | Clay: about 30%<br>Silt: about 70 %<br>Sand: –<br>Gravel: – | Clay: 13%<br>Silt: 74%<br>Sand: 13%<br>Gravel: – | Clay: 24%<br>Silt: 62%<br>Sand: 13%<br>Gravel: 1% |
| Specific weight [$N/m^3$] | 26868 | 26476 | 26868 |
| Cohesion [Pa] | 3000 ** | 19000 | 17000 |
| Friction angle [°] | 29 ** | 30 | 26 |
| Minerals | Quartz, Carbonates, Kaolinite, Smectites, Chlorites, Feldspars, Illites – Mica | – | Quartz, Carbonates, Kaolinite, Smectites, Chlorites, Feldspars, Mica, Plagioclases |
| Carbonates [%] | 15 | 21 | Mean value for Langhe marl: 22<br>4 (L) ***<br>15 (A) *** |
| Methylene blue value [l/kg] | – | 2.70 | 2.67 |

* surveyed on the sliding surface (Simeoni, 1998); ** from tests on the same soil (Caruso, 2002); *** L: surveyed in sliding surface layer; A: surveyed in altered rock adjacent to sliding surface layer

### *3.1 Laboratory tests on samples*

Tests on small samples were performed in two steps:

- Step 1: characterization of natural soil with 3 different percentages of carbonates content;
- Step 2: use of low potential direct currents in samples of saturated cohesive soil.

Dedicated devices were constructed to perform the 11 tests of Step 2 (1 calibration test and 10 actual tests) (Table

2). Each of these devices is composed by a Plexiglas cylinder (internal diameter = 0.09 m) containing saturated soil to be treated, equipped with two electrodes that are connected with a stabilized power supply that produces direct current (Fig. 1a). The system is also equipped with a third water tank, connected with the anode tank in order to guarantee continuous water procurement (Fig. 1a). A water container and a graphite electrode are located at each of the two ends of the cylinder (Fig. 1b); each container is equipped with a blowhole for allowing gas produced by the hydrolysis to leak. The soil is separated from the tank by means of a paper filter and a rigid porous filter (Fig. 1b), which is waterproof in its upper sector in order to prevent gas to come in contact with the soil.

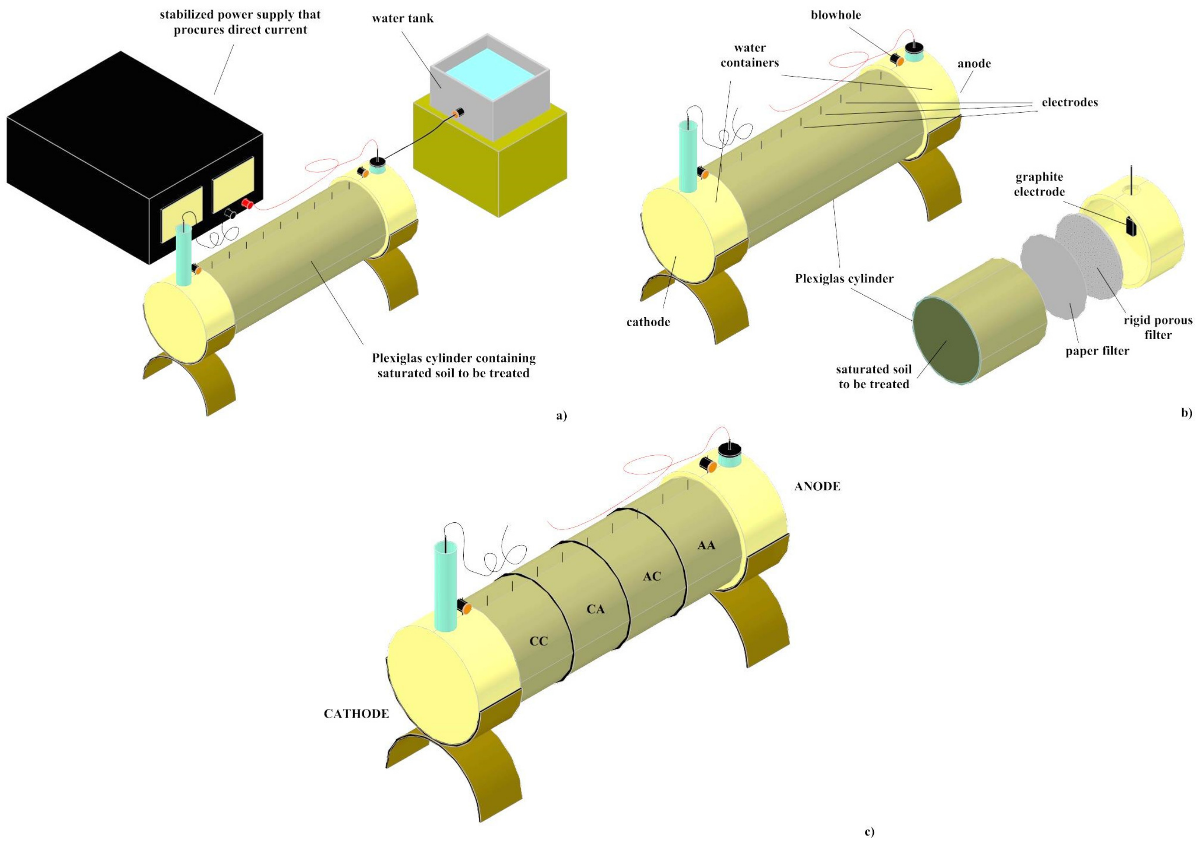

Figure 1. Dedicated devices: a) global view of the system; b) detail of the cylinder; c) sectors gas to be exposed to the soil.

Table 2. Number of tested samples as a function of different variables of step 2.

<table>
<tr><td>Process duration [days]<br>Electric field intensity [V/m]</td><td>15</td><td>30</td><td>60</td></tr>
<tr><td>10</td><td>1</td><td>1</td><td>1</td></tr>
<tr><td>100</td><td>1</td><td>1</td><td>---</td></tr>
<tr><td colspan="4">Electric field intensity [V/m] = 10<br>Process duration [d] = 60</td></tr>
<tr><td colspan="2">Different density</td><td colspan="2">Interaction with rain water after treatment and drying</td></tr>
<tr><td colspan="2">3</td><td colspan="2">2</td></tr>
</table>

These elements allow the hydraulic connection of all the systems: input water coming from the anode can pass through all of the system and pour out towards the cathode tank. Step 1 was aimed at the preparation of three samples of “natural” (not treated) soil, each containing a different carbonates content, in order to make comparison with soil treated with the proposed method. Carbonates content measured in a sample of Viadana silt is equal to 21% (Table 1). A second sample of this soil was processed in order to reduce carbonates content to 12%, while another sample was processed in order to increase it to 28%. During Step 2, two parameters were varied: intensity of electric field (10 – 100 V/m) and process duration (15 - 30 - 60 days). At the time of sample preparation, water content (about 47% - 54%) was greater than liquid limit. Each sample, at the end of the treatment, was divided in 4 sectors of equal volume (anode **AA, AC, CA, CC** cathode) (Fig. 1c), to be analyzed separately. The following parameters were measured in the three samples obtained in Step 1 and in all the samples obtained in Step 2: carbonates content (check), pH and VB, while peak shear strengths for both kinds of samples were then estimated by means of shear tests.

*3.2 Tests on slope physical models*

Nine physical models reproducing simplified slopes were built by creating and compacting many layers of Viadana silt at an average density of 1400 kg/m$^3$ (Fig. 2). Each model presented a plane inclined about 73° and humidity of the soil at the time of compaction was about 19%.

Tests on slope physical models were performed in two steps: Step A consisted of checking the behavior of 7 models composed by homogeneous unsaturated soil (without treatments); Step B consisted of checking of the behavior of 2 models, composed by homogeneous unsaturated soil, treated with a low potential direct current (20 V/m) for 60 days.

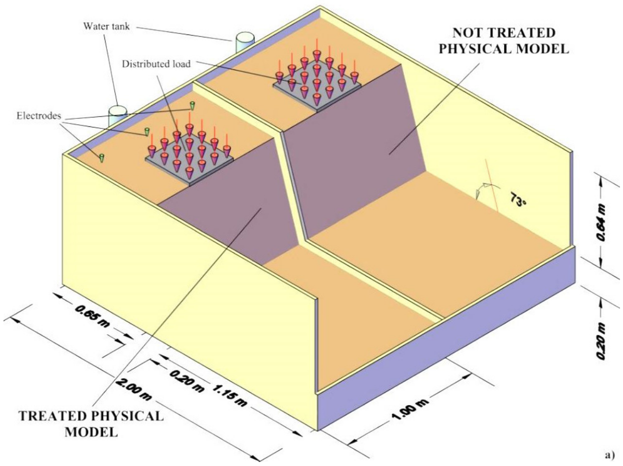


Figure 2. Scheme of the physical models.

## 4. Results and discussions

*4.1. Results of Step 1 and Step 2*

In Step 1, it was observed that increasing carbonates content from 12% to 28% caused Plastic Index (PI) and VB values to decrease, friction angle to increase and peak shear strength to increase.

In Step 2, it was observed that water content of the different treated samples tends to stabilize, independently from treatment duration and electric field intensity, around a value smaller than that surveyed during sample preparation (32% - 33%).

Carbonates content increases with treatment duration (Fig. 3a), becoming significant after 30 days. Considering the four sectors analyzed for each sample, it can be observed that swelling potential decreases from anode to cathode and friction angle increases by about 17% (Fig. 3b). By analyzing all the results, three correlations were identified: in general, pH and VB are inversely proportional (Fig. 4); water and carbonates content are inversely proportional (Fig. 5); by increasing treatment duration, carbonates content and friction angle increase, while VB decreases (Table 3).

Table 3. Correlation between treatment duration carbonates content, friction angle and potential swelling of soil, values referring to untreated soil are between brackets

| Features of electro osmotic process | Carbonate content [%] | Friction angle φ [°] | Methylene blue value [l/kg] |
|---|---|---|---|
| Duration [d]: 15<br>Electric potential [V]: 3<br>Specimen length [m]: 0.15 | 22 (21) | - | 2.7 (2.7) |
| Duration [d]: 30<br>Electric potential [V]: 5<br>Specimen length [m]: 0.27 | 22 (21) | 29 (30) | 2.7 (2.7) |
| Duration [d]: 60<br>Electric potential [V]: 5<br>Specimen length [m]: 0.27 | 24 (21) | 35 (30) | 2.5 (2.7) |

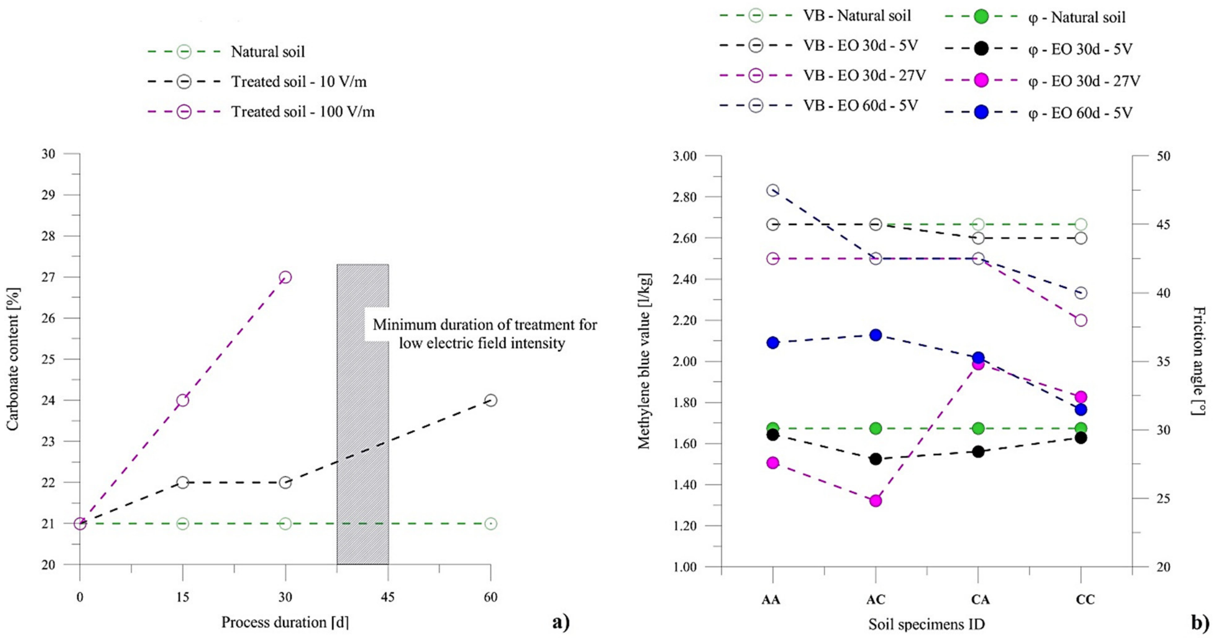


Figure 3. a) Carbonate content depending on process duration; b) comparison between Methylene blue value and friction angle.

### 4.3. Results of Step A and Step B

After the treatment was applied to physical models, tests on samples obtained from models showed that VB decreases, carbonates content increases while pH and water content are almost constant with respect to values obtained from untreated samples (Table 4). Dry soil's specific weight, consistently with increased carbonates content surveyed in treated soil, decreases after the treatment. In terms of failure pressure obtained by applying an increasing load to the models, an increase of about 35% of the mean failure pressure in treated models with respect to values obtained for untreated models was observed (Table 5).

VB, carbonates content and pH measured in unsaturated treated soil (Step B) were consistent with those measured in saturated soil after 60 days treatment (Step 2). Moreover, VB measured in Step B is 7.5% lower than VB of natural soil (Table 4).

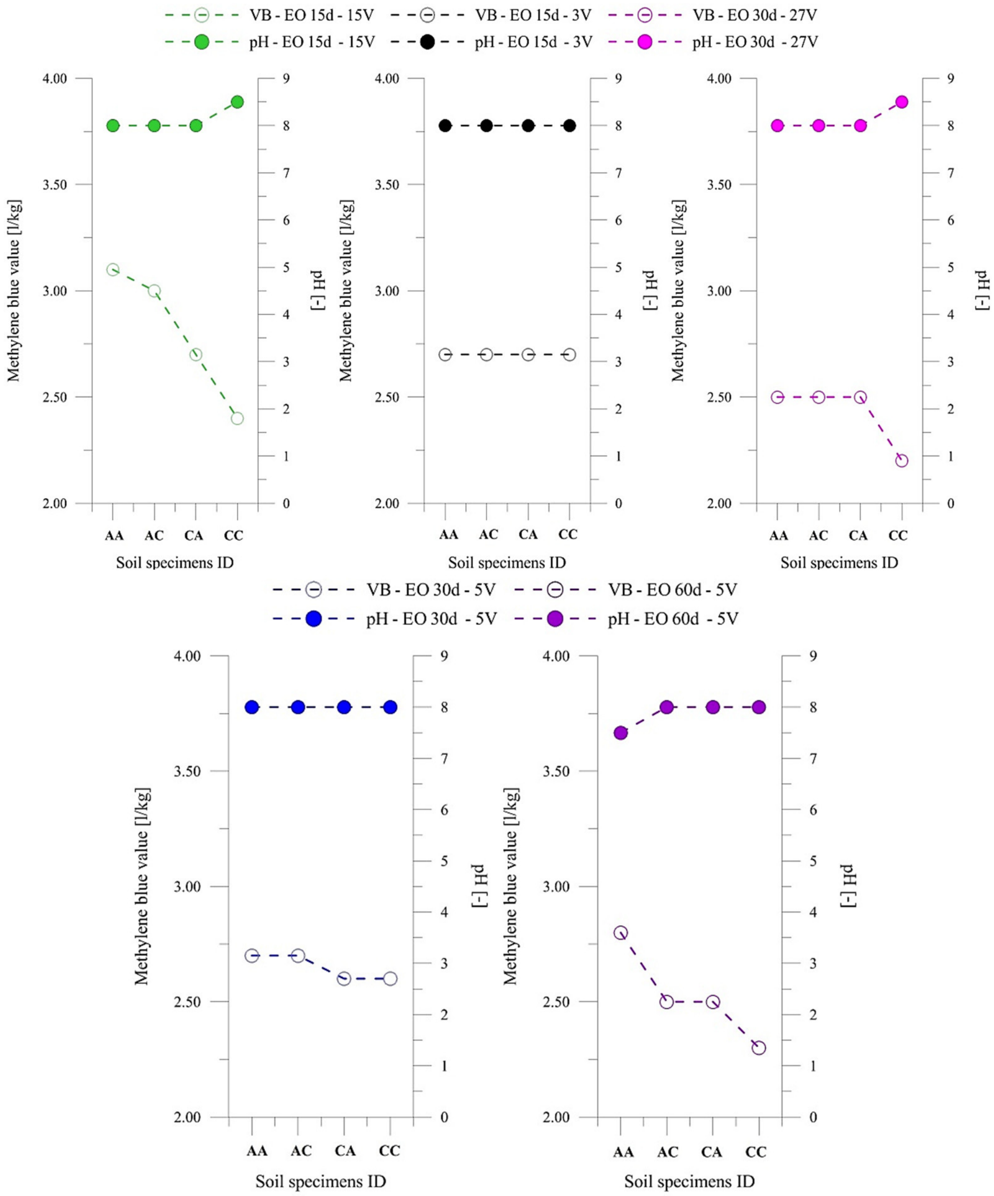


Figure 4. Comparison between Methylene blue value (VB) and pH.

Table 4. Comparison between Methylene blue values, carbonates content and pH measured in samples of soil obtained from physical models after 60 days treatment (Step B); values referring to untreated soil are between brackets (Step1).

| Physical model | Methylene blue value [l/kg] | Carbonates content [%] | pH [-] |
|---|---|---|---|
| T1 | 2.5 (2.7) | 23 (21) | 8 (8) |
| T2 | 2.5 (2.7) | 24 (21) | 8 (8) |

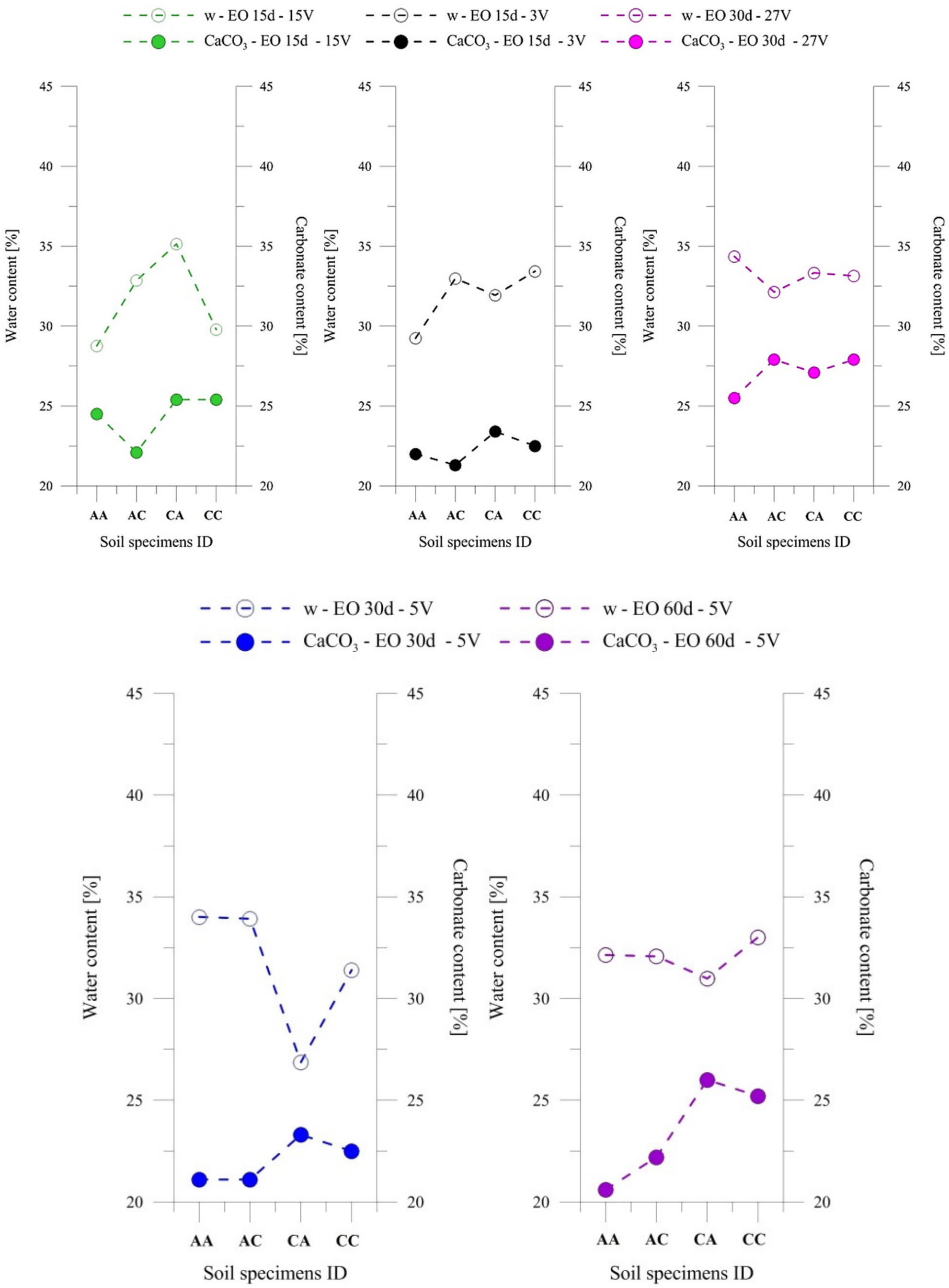


Figure 5. Comparison between water content (w) and carbonates content ($CaCO_3$).

Table 5. Parameters measured on physical models.

| | physical model id | specific weight $\gamma_d$ [N/m$^3$] | mean specific weight $\gamma_d$ [N/m$^3$] | water content w [%] | mean water content w [%] | failure pressure $p_f$ [Pa] | mean failure pressure $p_f$ [Pa] |
|---|---|---|---|---|---|---|---|
| Step A | NT 1 | 13728 | 13630 | 19.61 | 19.44 | 23700 | 27300 |
| | NT 2 | 12650 | | 19.82 | | 29300 | |
| | NT 3 | 13826 | | 19.88 | | 29300 | |
| | NT 4 | 13630 | | 20.70 | | 29300 | |
| | NT 5 | 14120 | | 20.55 | | 30700 | |
| | NT 6 | 13925 | | 17.15 | | 24400 | |
| | NT 7 | 13238 | | 18.38 | | 24400 | |
| Step B | T1 | 12846 | 12846 | 19.30 | 19.45 | 36300 | 37000 |
| | T2 | 12748 | | 19.60 | | 37700 | |

## 5. Conclusions

From the tests performed on small samples, it was observed that low potential direct currents (10 - 20 V/m) applied for 30 days to Viadana silt induce a reduction of smectite activity, a reduction and stabilization of water content, and an increase of friction angle. Moreover, carbonates precipitated where alkaline environment was introduced. From the tests performed on physical models, it was also observed that a 60 days treatment induced a reduction of smectite activity, a stabilization of water content and an increase of mean failure pressure, therefore an improvement of stability. In this kind of tests, carbonates precipitated where alkaline environment was introduced. In conclusion, from results of this preliminary research, an onsite application of the proposed methodology appears feasible and convenient in terms of costs and duration.

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